IMPROVEMENT OF THE VOLTAGE STABILITY IN THE DISTRIBUTION SYSTEM BY USING THE MULTIFUNCTIONAL DYNAMIC VOLTAGE RESTORER

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ABSTRACT

Dynamic voltage restorers (DVRs) are used to protect sensitive loads from the effects of voltage sags on the distribution feeder. This paper presents and verifies a novel voltage sag detection technique for use in conjunction with the main control system of a DVR. Also, the multiloop controller using the Posicast and P+Resonant controllers is proposed in order to improve the transient response and eliminate the steady-state error in DVR response, respectively. The proposed algorithm is applied to some disturbances in load voltage caused by induction motors starting, and a three-phase short circuit fault. Also, the capability of the proposed DVR has been tested to limit the downstream fault current. The current limitation will restore the point of common coupling (PCC) (the bus to which all feeders under study are connected) voltage and protect the DVR itself. The innovation here is that the DVR acts as virtual impedance with the main aim of protecting the PCC voltage during downstream fault without any problem in real power injection into the DVR. Simulation results show the capability of the DVR to control the emergency conditions of the distribution system

KEYWORDS: Dynamic Voltage Restorer (DVR), Emergency Control, Voltage Sag, Voltage Swell

INTRODUCTION

ADYNAMIC voltage restorer (DVR) is proposed for use in the medium-voltage or low-voltage distribution network to protect consumers from sudden sags in grid voltages. A typical DVR-connected distribution system is shown in Figure 1, where the DVR consists of essentially a series-connected injection Transformer, a voltage source inverter, an inverter output filter, and an energy storage device that is connected to the dc link. The power system upstream to the DVR is usually represented by an equivalent voltage source and source impedance connected in series. The basic operational principle of the DVR is to inject an appropriate voltage in series with the supply through an injection transformer when voltage sag is detected at the point of common coupling (PCC). Loads that are connected downstream are thus protected.

According to the definition and nature of voltage sag, it can be found that this is a transient phenomenon whose causes are classified as low- or medium-frequency transient events [2]. In recent years, considering the use of sensitive devices in modern industries, different methods of compensation of voltage sags have been used. One of these methods is using the DVR to improve the PQ and compensate the load voltage [6]–[13].

The main purpose is to detect and compensate for the voltage sag with minimum DVR active power injection [4], [5]. Also, the in-phase compensation method can be used for sag and swell mitigation [6]. The multiline DVR can be used for eliminating the battery in the DVR structure and controlling more than one line [7], [14]. A DVR [4]–[10] is primarily for use at the distribution level, where the basic principle is to inject a voltage in series with the supply when an upstream fault is detected. Loads connected downstream of the DVR are thus protected from any voltage sags caused by faults elsewhere on the network.

The location of the DVR, in terms of the connection arrangement of upstream transformers (typically) and the type of protection it is to offer to potentially sensitive loads, is a major factor when determining the type of inverter control required. The main DVR control used in conjunction with the sag detection techniques presented in this paper utilizes a type a vector control that only considers the positive and negative sequence information in the supply. The DVR is located downstream of a delta-star distribution transformer Figure 1, thus eliminating the need to control the zero sequence. In some methods, the main purpose is to detect and compensate for the voltage sag with minimum DVR active power injection [4], [5]. Also, the in-phase compensation method can be used for sag and swell mitigation [6]. The multiline DVR can be used for eliminating the battery in the DVR structure and controlling more than one line [7], [4]. Moreover, research has been made on using the DVR in medium level voltage [8]. Harmonic mitigation [8] and control of DVR under frequency variations [9] are also in the area of research. The closed-loop control with load voltage and current feedback is introduced as a simple method to control the DVR in [5]. Also, Posicast and P+Resonant controllers can be used to improve the transient response and eliminate the steady-state error in DVR. The Posicast controller is a kind of step function with two parts and is used to improve the damping of the transient oscillations initiated at the start instant from the voltage sag. The P+Resonant controller consists of a proportional function plus a resonant function and it eliminates the steady-state voltage tracking error [6]. The state feed forward and feedback methods [7], symmetrical components estimation [8], robust control [9], and wavelet transform [2] have also been proposed as different methods of Controlling the DVR

In this paper, a multifunctional control system is proposed in which the DVR protects the load voltage using Posicast and P+Resonant controllers when the source of disturbance is the parallel feeders. On the other hand, during a downstream fault, the equipment protects the PCC voltage, limits the fault current, and protects itself from large fault current. Although this latest condition has been described in [6] using the flux control method, the DVR proposed there acts like a virtual inductance with a constant value so that it does not receive any active power during limiting the fault current. But in the proposed method when the fault current passes through the DVR, The basis of the proposed control strategy in this paper is that when the fault current does not pass through the DVR, an outer feedback loop of the load voltage with an inner feedback loop of the filter capacitor current will be used. Also, a Feed Forward loop will be used to improve the dynamic response of the load voltage. Moreover, to improve the transient response, the Posicastcontroller and to eliminate the steady-state error, the P+Resonantthrough the DVR, using the flux control algorithm [7], the series voltage is injected in the opposite direction and, therefore, the DVR acts like series variable impedance.

DVR COMPONENTS AND ITS BASIC OPERATIONAL PRINCIPLE
DVR Components

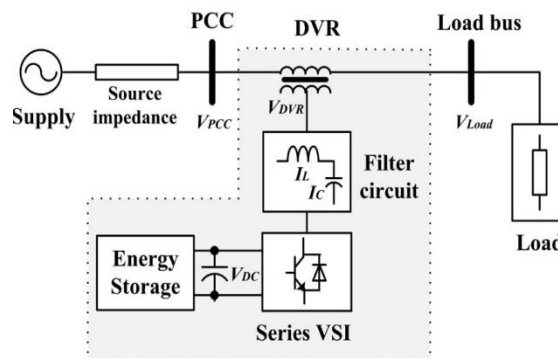A typical DVR-connected distribution system is shown in the Figure 1

Figure 1: Typical DVR-Connected Distribution System

Where the DVR consists of essentially a series-connected injection transformer, a voltage-source inverter, an inverter output filter, and an energy storage device that is connected to the dc link. Before injecting the inverter output to the system, it must be filtered so that harmonics due to switching function in the inverter are eliminated. It should be noted that when using the DVR in real situations, the injection transformer will be connected in parallel with a bypass switch (Figure 1). When there is no disturbances in voltage, the injection transformer (hence, the DVR) will be short circuited by this switch to minimize losses and maximize cost effectiveness.

Also, this switch can be in the form of two parallel thyristors, as they have high on and off speed [7]. A financial assessment of voltage sag events and use of flexible ac transmission systems (FACTS) devices, such as DVR, to mitigate them is provided in [2]. It is obvious that the flexibility of the DVR output depends on the switching accuracy of the pulse width modulation (PWM) scheme and the control method. The PWM generates sinusoidal signals by comparing a sinusoidal wave with a saw tooth wave and sending appropriate signals to the inverter switches. A further detailed description about this scheme can be found in [3].

Basic Operational Principle of DVR

The DVR system shown in Figure 1 controls the load voltage by injecting an appropriate voltage pharos in series with the system using the injection series transformer. In most of the sag compensation

Techniques, it is necessary that during compensation, the DVR injects some active power to the system.
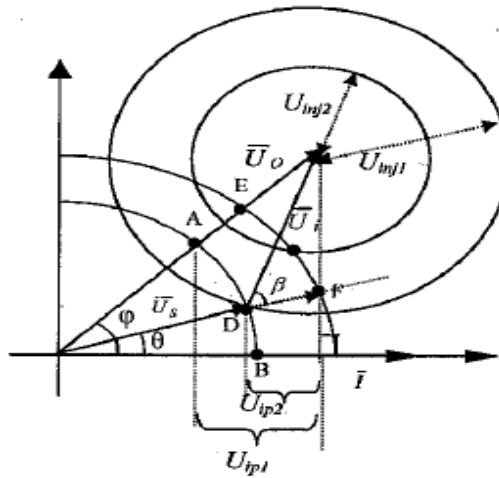

Figure 2: Pharos Diagram of the Electrical Conditions

During a Voltage Sag

The pharos diagram in Figure 2 shows the electrical conditions during voltage sag, where, for clarity, only one phase is shown. VoltagesV1V2and Vdvr, and are the source-side voltage, the load side voltage, and the DVR injected voltage, respectively. Also, the operators I, φ δ and α and are the load current, the load power factor angle, the source phase voltage angle, and the voltage phase advance angle, respectively [4]. It should be noted that in addition to the in-phase injection technique, another technique, namely "the phase advance voltage compensation technique" is also used

Due to the existence of semiconductor switches in the DVR inverter, this piece of equipment is nonlinear. However, the state equations can be linear zed using linearization techniques. The Dynamic characteristic of the DVR is influenced by the filter and the load. Although the modeling of the filter (that usually is a simple LC circuit) is easy to do, the load modeling is not as simple because the load can vary from a linear time invariant one to a nonlinear time-variant one. In this paper, the simulations are performed with two types of loads:

- A constant power load and

- A motor load.

As figure 3 shows, the load voltage is regulated by the DVR through injecting Vdvr. For simplicity, the bypass switch shown in Figure 1 is not presented in this figure. Here, it is assumed that the load has a resistance(R*l*) and an inductance (L*l*) The DVR harmonic filter has an inductance of, a resistance (R*l*) of, and capacitance(C*l*) of. Also, the DVR injection transformer has a combined winding resistance of, a leakage inductance of, and turns ratioof1:n The Posicast controller is used in order to improve the transient response. Figure 3 shows a typical control block diagram of the DVR. Note that because in real situations, we are dealing with multiple feeders connected to a common bus, namely "the Point of Common Coupling (PCC)," from now on, V1andV2 will be replaced Vpcc and VL respectively to make a generalized sense as show on the source side of the DVR (Vpcc) is compared with a load-side reference voltage (VL) so that the necessary injection voltage is derived. A simple method to continue is to feed the error signal into the PWM inverter of the DVR. But the problem with this is that the transient oscillations initiated at the start instant from the voltage sag could not be damped sufficiently. To improve the damping, as shown in Figure 4, the Posicast controller can be used just before transferring the signal to the PWM inverter of the DVR.
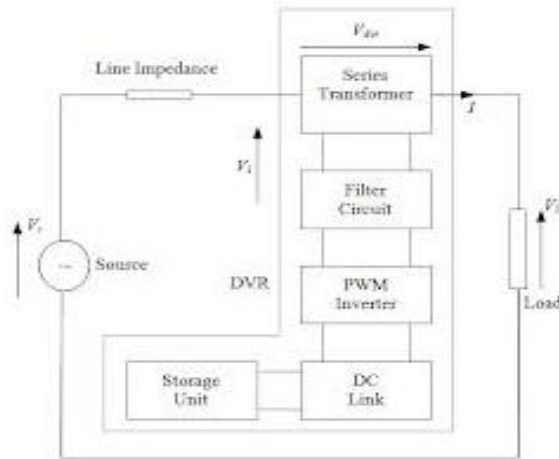

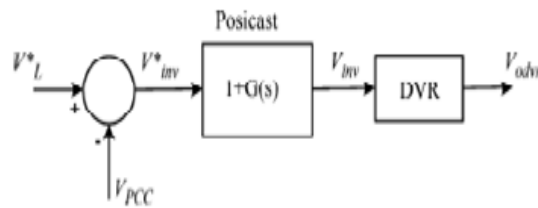**Figure 3: Distribution System with the DVR**

Figure 4: Open-Loop Control Using the Posicast

Controller

The transfer functions of the controller can bedescribedas follows:

$$1 + G(s) = 1 + \frac{\delta}{1+\delta}(e^{-s\frac{Td}{2}} - 1)$$ (1)

where δ and Td are the step response overshoot and the period of damped response signal, respectively To find the appropriate values of $\delta$and Td, first the DVR model will be derived according to Figure 3 as follows:

$$V_i = V_e + I_f R_f + L_f \frac{dI_f}{dt}$$

$$I_f = I_e + n.I_t$$

$$I_c = C_f \frac{dV_e}{dt}$$

$$V_{dvr} = n\left[V_e - n\left(R_d I_t + L_i \frac{dI_t}{dt}\right)\right]$$

$$V_2 = V_1 + V_{dvr} \tag{2}$$

Then, according to (2) and the definitions of damping and the delay time in the control literature, and are derivedas follows:

$$Td = \frac{2\pi}{\omega_r} = \frac{\pi}{\sqrt{\frac{1}{L_f C_f} - \frac{R^2}{4L_f^2}}}$$

$$\delta = e^{\frac{\varepsilon\pi}{\sqrt{1-\varepsilon^2}}} = e^{-R_f\pi\sqrt{C_f}/\sqrt{L_f - R_f^2 C_f^2}} \tag{3}$$

The Posicast controller works by pole elimination and proper regulation of its parameters is necessary. For this reason, it is sensitive to inaccurate information of the system damping resonance frequency. To decrease this sensitivity, as is shown in Figure 5, the open-loop controller can be converted to a closed loop controller by adding a multiloop feedback path parallel to the existing feed forward path.
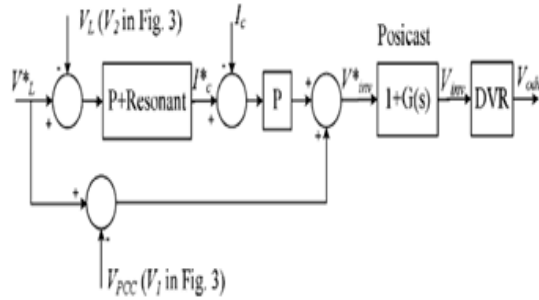

Figure 5: Multiloop Control Using the Posicast and P+Resonant Controllers

The feedback path consists of an outer voltage loop and a fast inner current loop. To eliminate the steady-state voltage tracking error (V*L-VL) computationally less intensive P+Resonant compensator is added to the outer voltageloop. Theideal P+Resonant compensate or can be mathematically expressed as

$$G_R(s) = K_p + \frac{2K_I s}{s^2 + \omega_0^2} \tag{4}$$

Where Kp and KI are gain constants and $\omega_0$is the controller resonant frequency. The ideal resonant controller, however, acts like a network with an infinite quality factor, which is not realizable in practice. A more practical compensators therefore used here, and is expressed as

$$G_R(s) = K_p + \frac{2K_I \omega_{cut} s}{s^2 + 2\omega_{cut} s + \omega_0^2} \tag{5}$$

Where ωcut is the compensator cutoff frequency which is 1 rad/s in this application

PROPOSED MULTIFUNCTIONAL DVR

In addition to the aforementioned capabilities of DVR, it can be used in the medium-voltage level (as in Figure 6) to protect a group of consumers when the cause of disturbance is in the downstream of the DVR's feeder and the large fault

current passes through the DVR itself. In this case, the equipment can limit the fault current and protect the loads in parallel feeders until the breaker works and disconnects the faulted feeder. The large fault current will cause the PCC voltage to drop and the loads on the other feeders connected to this bus will be affected. Furthermore, if not controlled properly, the DVR might also contribute to this PCC voltage sag in the process of compensating the missing voltage, hence further worsening the fault situation
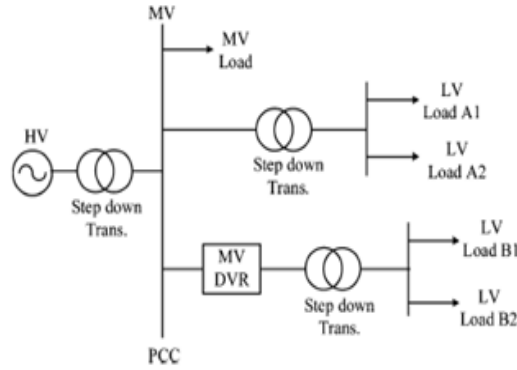
Figure 6: DVR Connected in a Medium-Voltage Level Power System

To limit the fault current, a flux-charge model has been proposed and used to make DVR act like a pure virtual inductance which does not take any real power from the external system and, therefore, protects the dc-link capacitor and battery as shown in Figure 1 [9]. But in this model, the value of the virtual inductance of DVR is a fixed one and the reference of the control loop is the flux of the injection transformer winding, and the PCC voltage is not mentioned in the control loop. In this paper, the PCC voltage is used as the main reference signal and the DVR acts like a variable impedance. For this reason, the absorption of real power is harmful for the battery and dc-link capacitor

PROPOSED METHOD FOR USING THE FLUX-CHARGE MODEL

In this part, an algorithm is proposed for the DVR to restore the PCC voltage, limit the fault current, and, therefore, protect the DVR components. The flux-charge model here is used in away so that the DVR acts as a virtual inductance with a variable value in series with the distribution feeder. To do this, the DVR must be controlled in a way to inject a proper voltage having the opposite polarity with respect to usual cases. It should be noted that over current tripping is not possible in this case, unless additional communication between the DVR and the downstream side over current circuit breaker (CB) is available. If it is necessary to operate the over current CB at PCC, communication between the DVR and the PCC breaker might have to be made and this can be easily done by sending a signal to the breaker when the DVR is in the fault-current limiting mode as the DVR is just located after PCC [11]. The proposed DVR control method is illustrated in Figure 8.
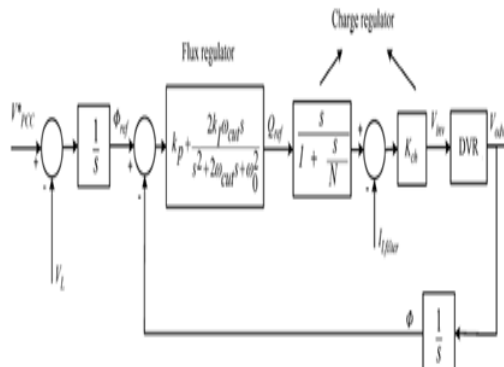

Figure 7: Proposed Method

It should also be noted that the reference flux(ϕ ref) is derived by integration of the subtraction of the PCC reference voltage and the DVR load-side voltage. In this control strategy, the control variable used for the outer flux model is the inverter-filtered terminal flux defined as

$$\varphi = \int V_{odvr} dt \tag{6}$$

Where Vodvt is the filter capacitor voltage of the DVR The flux error is then fed to the flux regulator, which is a P+Resonant controller, with a transfer function given in (6). On the other hand, it can be shown that a single flux-model would not damp out the resonant peak of the LC filter connected to the output of the inverter. To stabilize the system, an inner charge model is therefore considered. In this loop, the filter inductor charge, which is derived by integration of its current, tracks the reference charge output of the flux regulator. The calculated charge error is then fed to the charge regulator with the transfer function

$$G_{charge}(s) = k_{Ch} \frac{s}{1+\frac{s}{N}} \tag{7}$$

Which is actually a practical form of the derivative controller. In this transfer function, the regulator gain is limited to N at high frequencies to prevent noise amplification.

The derivative term in $\left(\frac{s}{1+\frac{s}{N}} \right)$ neutralizes effects of voltage and current integrations at the inputs of the flux-charge model, resulting in the proposed algorithm having the same regulation performance as the multiloop voltage-current feedback control, with the only difference being the presence of an additional low–pass filter in the flux control loop in the form of $\left(\frac{s}{1+\frac{s}{N}} \right)$. The bandwidth of this low–pass filter is tuned (through varying) with consideration for measurement noise attenuation, DVR LC-filter transient resonance attenuation, and system stability margins.

SIMULATION CIRCUIT AND RESULTS

In this part, the proposed DVR topology and control algorithm will be used for emergency control during the voltage sag. The three-phase short circuit and the start of a three-phase large induction motor will be considered as the cause of distortion in the simulations.

Under Study Test System

In this paper, the IEEE standard 13-bus balanced industrial system will be used as the test system. The one-line diagram of this system is shown in Figure 9.
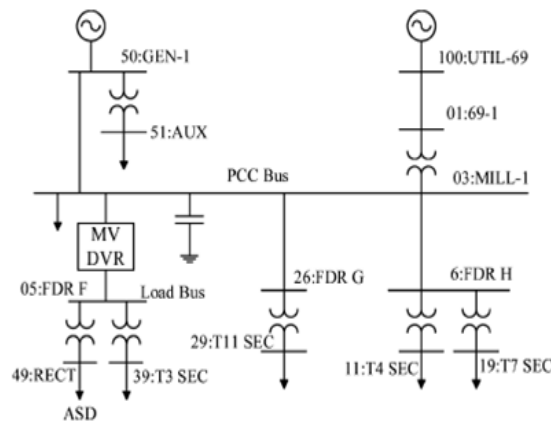

Figure 8: Under Study Test System

Simulation Circuit Diagram

- **Three-Phase Short Circuit**

The DVR will start the compensation just after the detection of sag. As can be seen in the enlarged figure, the DVR has restored the voltage to normal form with attenuation of the oscillations at the start of the compensation in less than half a cycle. It is worth noting that the amount and shape of the oscillations depends also on the time of applying the fault. As can be seen in the enlarged figure, the voltage value of phase B is nearly zero; this phase has minimum oscillation when fault starts
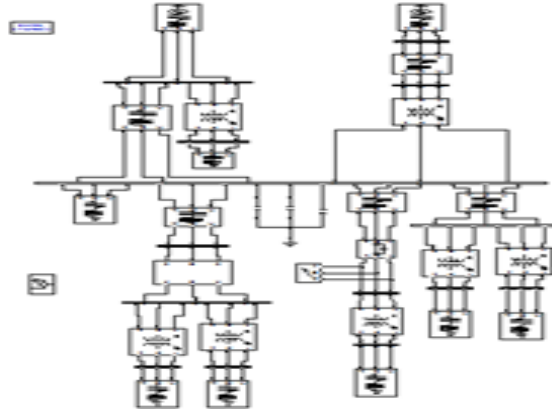
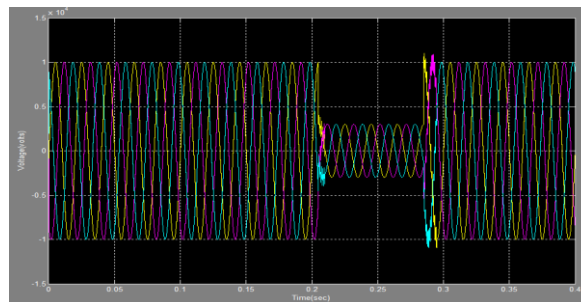**Figure 9: Simulation Circuit Diagram under Three Phase Short Circuit**

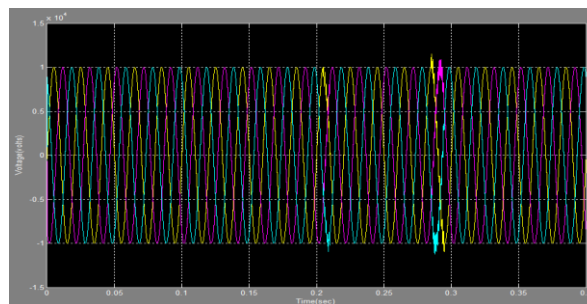**Figure 10: Three-Phase PCC Voltages under Fault Conduction**

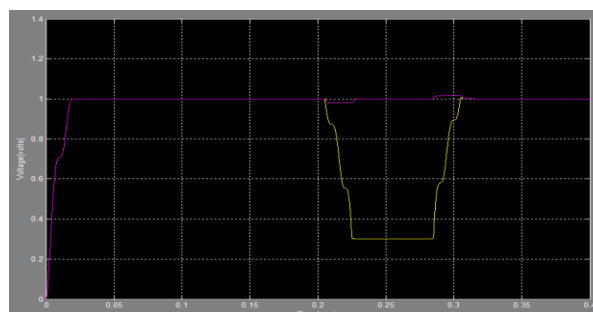**Figure 11: Three-Phase PCC Voltages under Fault is Compensation by DVR**

Figure 12: RMS Voltages of PCC and Load

Starting the Induction Motor

The simulation circuit diagram of the large induction motor as show in the figure 14 below
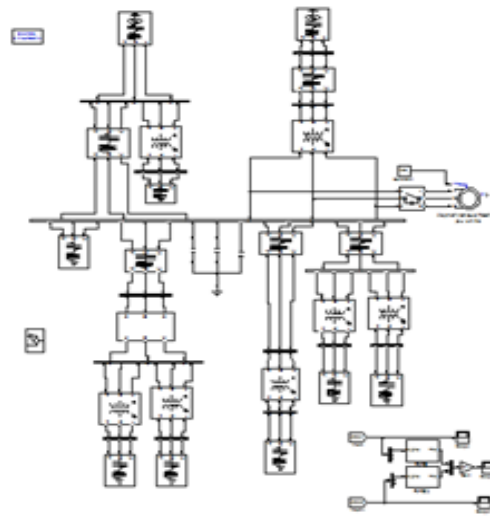

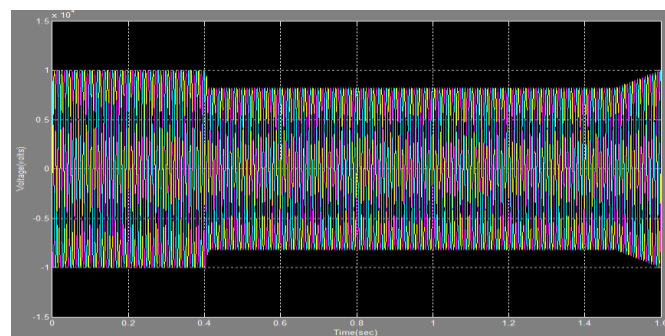**Figure 13: Simulation Circuit Diagram of the Starting of Induction Motor**

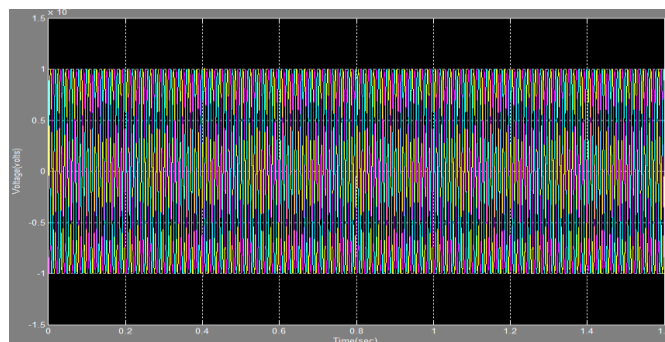**Figure 14: Three Phase PCC Voltages at the Starting of the Induction Motor**

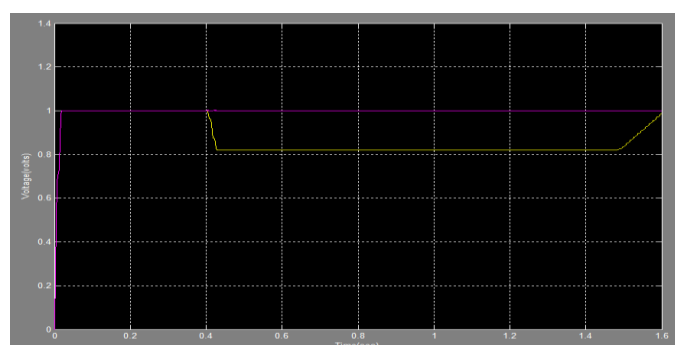**Figure 15: Three-Phase Load Voltages is Compensation by DVR**

Figure 16: RMS Voltages of PCC and Load

Fault Current Limiting

The last simulation is run for a symmetrical downstream fault, and the capability of the DVR to reduce the fault current and restore the PCC voltage is tested. For this purpose, a three-phase short circuit is applied on bus In Figure 17, the fault

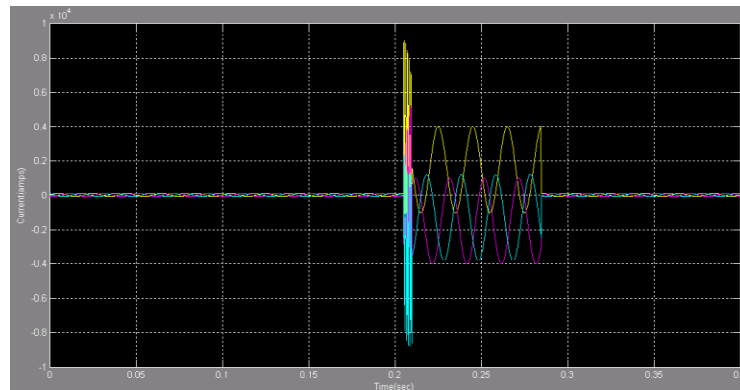Current, without the DVR compensation, is shown.

Figure 17: Current Wave Shape Due to the Three-Phase Short-Circuit Fault without DVR Compensation

CONCLUSIONS

In this paper, a multifunctional DVR is proposed, and a closed-loop control system is used for its control to improve the damping of the DVR response. Also, for further improving the transient response and eliminating the steady-state error, the Posicast and P+Resonant controllers are used. As the second function of this DVR, using the flux-charge model, the equipment is controlled so that it limits the downstream fault currents and protects the PCC voltage during these faults by acting as variable impedance.

REFERENCES

1. P. Hcine and M. Khronen, "Voltage sag distribution caused by power system faults," *IEEE Trans. Power Syst.*, vol. 18, no. 4, pp. 1367–1373, Nov. 2003.

2. S. S. Choi, B. H. Li, and D. M. Vilathgamuwa, "Dynamic voltage restoration with minimum energy injection," *IEEE Trans. Power Syst.*, vol. 15, no. 1, pp. 51–57, Feb. 2000.

3. C. Fitzer, M. Barnes, and P. Green, "Voltage sag detection technique for a dynamic voltage restore," IEEE Trans. Ind. Appl., vol. 2, no. 1, pp. 203–212, Jan./Feb. 2004.

4. C. Benachaiba and B. Ferdi, "Voltage quality improvement using DVR," Electt. Power Qual. Utilisation, Journal, vol. XIV, no. 1, 2008.

5. P. C. Loh, D. M. Vilathgamuwa, S. K. Tang, and H. L. Long, "Multilevel dynamic voltage restorer," *IEEE Power Electron. Lett.*, vol. 2, no. 4, pp. 125–130, Dec. 2004.

6. E. Babaei, M. Farhadi, and M. Sabahi, "Compensation of voltage disturbances in distribution systems using single-phase dynamic voltage restorer," *Elect. Power Syst. Res.*, Jul. 2010.

7. C. N.-M. Ho and H. S.-H. Chung, "Implementation and performance evaluation of a fast dynamic control scheme for capacitor-supported interline DVR," *IEEE Trans Power Electron.*, vol. 25, no. 8, pp. 1975–1988, Aug. 2010.

8.   M. Vilathgamuwa, A. A. D. R. Perera, and S. S. Choi, "Performance improvement of the dynamic voltage restorer with closed-loop load voltage and current-mode control," *IEEE Trans. Power Electron.*, vol. 17, no. 5, pp. 824–834, Sep. 2002.

9.   M. Vilathgamuwa, A. A. D. R. Perera, and S. S. Choi, "Performance improvement of the dynamic voltage restorer with closed-loop load voltage and current-mode control," *IEEE Trans. Power Electron.*, vol. 17, no. 5, pp. 824–834, Sep. 2002.

10. Y. W. Li, P. C. Loh, F. Blaabjerg, and D. M. Vilathgamuwa, "Investigation and improvement of transient response of DVR at medium voltage level," *IEEE Trans. Ind. Appl.*, vol. 43, no. 5, pp. 1309–1319, Sep./Oct. 2007.

11. H. Kim and S. K. Sul, "Compensation voltage control in dynamic voltage restorers by use of feed forward and state feedback scheme," *IEEE Trans. Power Electron.*, vol. 20, no. 5, pp. 1169–1177, Sep. 2005.

12.   M. I. Marei, E. F. El-Saadany, and M. M. A. Salama, "A new approach to control DVR based on symmetrical components estimation," *IEEE Trans. Power Del.*, vol. 22, no. 4, pp. 2017–2024, Oct. 2007.

13. Y. W. Li, D. M. Vilathgamuwa, F. Blaabjerg, and P. C. Loh, "A robust control scheme for medium-voltage-level DVR implementation," *IEEE Trans. Ind. Electron.*, vol. 54, no. 4, pp. 2249–2261, Aug. 2007.

14. S. A. Saleh, C. R. Moloney, and M. A. Rahman, "Implementation of a dynamic voltage restorer system based on discretewavelet transforms," *IEEE Trans. Power Del.*, vol. 23, no. 4, pp. 2360–2375, Oct. 2008.

15. H. Awad, J. Svensson, and M. Bollen, "Mitigation of unbalanced voltage dips using static series compensator," *IEEE Trans Power Electron.*, vol. 19, no. 3, pp. 837–846, May 2004.

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